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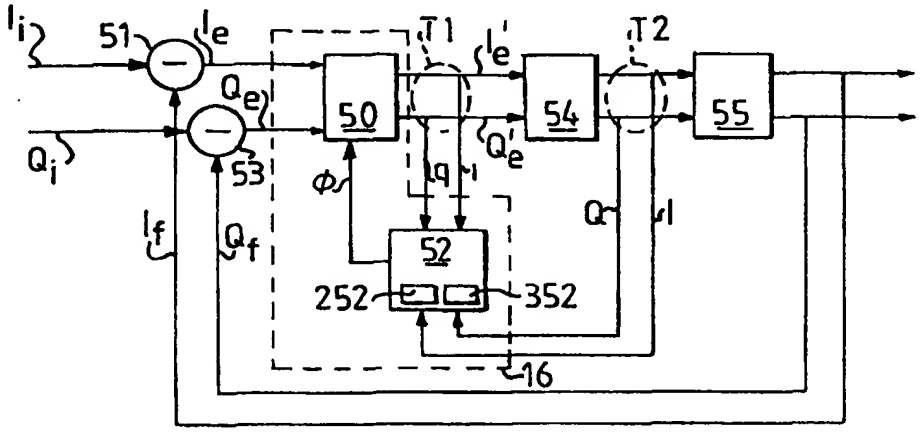

(57) Abstract

According to the invention, a Cartesian control means (16) comprising a phase rotator (50) and a phase adjuster (52) is provided. With a method and a device according to the invention, a system is provided that is unconditionally stable with respect to non-phase alignment, regardless of input power changes, temperature and component ageing. No certain conditions need to be placed upon the control system to ensure stability, i.e. the system is non-obtrusive and requires no off-line calibration. The inclusion of the phase rotator (50) and phase adjustment techniques into the Cartesian control system makes this possible.

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METHOD AND DEVICE IN A TELECOMMUNICATION SYSTEM

Technical Field of the Invention

The present invention relates to Cartesian control systems.

Description of Related Art

In a telecommunication system, particularly in RF applications, efficient methods of linearisation are called for in order to minimize intermodulation, one cause of which being the distortion generated by non-linearities in power amplifiers.

In wide band systems, there are two main methods for dealing with distortion of amplifiers; predistortion and feedforward. Predistortion means that the distortion introduced by the main amplifier is inversely modelled and applied at the input of the amplifier, thereby making the total, ideally, equal to a power independent constant.

The feedforward technique consists basically of two independent steps. The first step is to extract the distortion introduced by the main amplifier on the signals to be amplified. This is referred to as extracting an error signal. The second step is to inject this error signal in anti-phase and time-aligned at the output of the feedforward amplifier to thereby cancel out the distortion. The performance of the feedforward technique is dependent upon the ability to add rotated signal vectors correctly in anti-phase and equal amplitude.

US patent 5,157,346 to Powell et. al. discloses a feedforward lineariser with a Cartesian control system. Cartesian control in this case refers to the combination of complex Cartesian correlation detection followed by linear Cartesian feedback control.

US patent 5,134,718 to Gailus discloses a method and device for correcting an initial phase relationship in a linear transmitter between an input signal and an input feedback signal, opening the feedback loop (open loop) and then calculating the phase from special injected training signals. The method of opening the feedback loop inherently has the disadvantageous consequence of interrupting the normal operation of the feedback loop, thereby causing disturbances in the system. Such a method is to be considered as an obtrusive method because it interrupts the normal operation of the feedback loop.

WO94/05078 to Bergsten and Nyström discloses a method of correcting the phase relationship within a Cartesian feedback loop at intermediate frequency.

Summary

In a Cartesian control system, the phase between the feedback and the input signals change with temperature, component ageing and input power etc. If Cartesian feedback and input signals are not phase-aligned then stability can be compromised. It is thus desirable to track and adjust these phase changes to ensure stability.

Dependencies on temperature, component ageing and input power etc. can alternatively be characterized and system parameters modified to allow for better start-up operation. This can be considered as an obtrusive phase adjuster technique, which requires off-line calibration. Such interruptions to normal operation are inconvenient if not unacceptable to the operation of most systems e.g. feedforward linearisers. Additionally, such modifications will lower the potential bandwidth, or speed, of the control system. Further, these modifications do not change the fact that the system is conditionally stable, therefore instability can still occur during operation.

Accordingly, it is an object of the present invention to provide a non-obtrusive control means for a Cartesian control system, said control means providing unconditional stability with respect to misalignment in phase between the feedback and input signals.

A further object of the invention is to provide a non-obtrusive method and device for a Cartesian control system that is unconditionally stable without reducing bandwidth or accuracy in the system.

A further object of the invention is to provide a method and a device for keeping feedback signals and input signals phase-aligned within a Cartesian control system in general.

Another object of the present invention is to provide a method and a device for a feedforward lineariser for RF-applications that is unconditionally stable.

Another object of the invention is to provide a method and a device for a phase adjuster technique for use in a feedforward lineariser, which is non-obtrusive to normal operation, i.e. requiring no off-line calibration.

Another object of the present invention is to provide a method and a device for a Cartesian feedback transmitter that is unconditionally stable.

Another object of the invention is to provide a method and a device for a phase adjuster technique for use in a Cartesian feedback transmitter, which is non-obtrusive to normal operation, i.e. requiring no off-line calibration.

These objects are achieved by a method and a device having the characterizing features of the independent claims. Further features and improvements of the invention, are given in the dependent claims.

According to the invention, a Cartesian control system is provided having a linear Cartesian loop feedback control system comprising a phase rotator and a phase adjuster. With a method and a device according to the invention, a system is provided that is unconditionally stable with respect to non-phase alignment, regardless of input

power changes, temperature, manufacturing spread, component ageing etc. No certain conditions need to be placed upon the control system to ensure stability, and the system is non-obtrusive and requires no off-line calibration. The inclusion of the phase rotator and phase adjustment techniques into the Cartesian control system makes this possible.

Because the feedback and input Cartesian signals are kept phase-aligned, the stability margin requirements can be reduced. If this is applied to a known system, a wider bandwidth, i.e. a faster control technique can be achieved with the given stability margin. Thus a system is provided that is unconditionally stable without reducing the bandwidth or accuracy of said system.

Brief Description of the Drawings

For a more complete understanding of the present invention and for further objects and advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings, in which:

Figure 1 shows a feedforward linear amplifier with a control system according an embodiment of to the invention.
Figure 2A shows an embodiment of a Cartesian control system including a supervisory control loop having a controller.
Figure 2B shows another embodiment of a Cartesian control system including a supervisory control loop having a controller.
Figure 2C shows yet another embodiment of a Cartesian control system including a supervisory control loop having a controller.
Figures 3A, 3B, and 3C show another three embodiments of a Cartesian control system including a supervisory control loop having a controller.
Figure 4 shows a flow chart of a phase adjustment method according to an embodiment of the invention.

Figure 5 shows a Cartesian feedback transmitter according to an embodiment of the invention.

Figure 6A and 6B is a flow chart illustrating an embodiment of a method according to the invention.

Figure 7 is a block diagram of an embodiment of a controller.

Detailed Description of Embodiments

Fig. 2A is a block diagram showing an embodiment of a Cartesian control system. The Cartesian control system receives input signals I_i, Q_i to subtractors 51,53 which also receive feedback signals I_f, Q_f. The subtractors generate error signals, which are delivered to a controlled phase rotator 50. The outputs I'_e, Q'_e are delivered to a filter unit 54, the outputs of which are delivered to a system to be controlled 55. The output of the system to be controlled 55 is tapped, used for feedback signals I_f, Q_f and delivered to the subtractors 51,53, as described above. The above described components form a control loop in a Cartesian control system.

According to an embodiment of the invention the Cartesian control system includes a controller 16. The controller 16 is coupled to the control loop of the Cartesian control system so as to enable reception of first signals i,q originating from a first location T1 of the Cartesian control system, as well as reception of second signals I,Q originating from a second location T2 of the Cartesian control system.

Figure 6

Figure 6 is a flow chart for illustrating an embodiment of a method of compensating a phase rotation in a control loop.

In a first step S600, a phase rotation between signals at the first location T1 and the second location T2 is measured or estimated. This is achieved by receiving a first signal pair i,q from location T1 (step S610), and by receiving a second signal pair I,Q

from location T2. Thereafter, a set of differential signal values $\Delta i, \Delta q, \Delta I, \Delta Q$ are generated (step S630).

A phase parameter θ is generated in dependence of the differential signal values (step S640). The phase parameter θ is indicative of a phase rotation in the control loop between the first location T1 and the second location T2. According to one embodiment of step S640 the phase parameter θ is calculated as:

$$\theta = \tan^{-1}\theta_2$$

where $$\theta_2 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\Delta q \times \Delta Q + \Delta i \times \Delta I}$$

In a subsequent step, S650, a first phase value $\phi(n)$ is generated. The phase value $\phi(n)$ is calculated in dependence of the phase parameter θ. The first phase value, generated in step S650, is stored in a memory for use in subsequent steps of this method (step S660).

Thereafter, step S670, a signal pair to be rotated I_eQ_e is received. In step S680, a rotated first signal I' is generated in dependence of the first phase value $\phi(n)$ and the signal I_e to be rotated. A rotated second signal Q' is generated in a corresponding manner (step S690).

The rotation provided by step S670 - S690 is made for the purpose of compensating the detected phase rotation θ.

In step S700, the controller 16 receives two new sets of signals i,q and I,Q. Thereafter, in step S710, the controller 16 generates differential signal values $\Delta i, \Delta q$ and $\Delta I, \Delta Q$. And in response to the differential signal values, a new estimate θ is generated. The new estimate θ can be obtained in a simplified manner, allowing for a quicker calculation method.

Whereas the phase parameter θ in the above step S630 is calculated using an inverse tangent calculation, the simplified estimate obtained according to step S720 requires only two multiplications and one subtraction:

$$\theta = \Delta q \times \Delta I - \Delta i \times \Delta Q$$

Therefore, this simplified method step S720 can be performed at a quicker rate than the above described method step S640.

In a subsequent step, S730, the first phase value $\phi(n)$, which was stored in the above described step S660, is retrieved. Thereafter (step S740) a test is performed so as to determine whether the new estimated phase parameter θ has a positive sign or a negative sign. If the sign of the phase parameter generated in step S720 is positive, then a new phase value $\phi(n+1)$ is set to a value higher than the first phase value $\phi(n)$. According to step S750, the new phase value is obtained by adding a suitable number k of radians to the retrieved phase value $\phi(n)$. The value k to be added may be only a fraction of a radian.

If, on the other hand, the sign of θ is negative, then the new phase value $\phi(n+1)$ is set to a lower value than the previous phase value $\phi(n)$.

After the generation of the new phase value $\phi(n+1)$, this value is stored so as to replace the earlier phase value $\phi(n)$, step S770. Thereafter, the method is repeated, starting with the above described step S670 so as to rotate a pair of signals to be rotated by the new phase value ϕ.

Figure 1

Fig 1 illustrates a feedforward lineariser according to an embodiment of the invention. The lineariser includes three controller 16,26,38 according to a first embodiment of the invention.

The controller according to the first embodiment of the invention controls the inputs of a Quadrature Gain and Phase Adjuster (QGPA). Note that a detector scheme that produces Cartesian error signals is required prior to the control means 16,26,38, e.g. a Complex Cartesian Correlator or a Pilot recovery and Quadrature down conversion circuit. There are three QGPA:s in the illustrated lineariser.

In the following description similar or identical features in different embodiments will be indicated by the same reference numerals. In some instances, however, there are different reference numerals for features that operate in a similar manner e.g. control means 16,26,38 indicating similar control means at different positions in the feed-forward lineariser according to Fig 1.

Control means according to embodiments of the invention are here shown to control all three QGPA:s but other embodiments are readily understood by the man skilled in the art, the control means being used to control one or more of the QGPA:s of a feed-forward lineariser. The invention is hereby described as a digital system, but it is obvious to the man skilled in the art that the inventive concept may be applied to a system comprising analogue parts as well.

A multi carrier signal s_{in} to be linearised is fed to a first QGPA 3 via an input 2 of the lineariser. From the first QGPA 3, where the signal can be gain and phase adjusted, the signal is forwarded to a pilot insertion means 4 by which a pilot signal, generated in a pilot generator 5, is inserted into the signal. The resulting signal is fed to an MPA 7 (main power amplifier). The signal is amplified in the MPA 7 and subsequently delayed in a first delay means 6, then fed to a first subtractor 8. The input signal s_{in} is delayed in a second delay means 10 and combined in a second subtractor 12 with the output signal of the MPA 7 after this output signal has been attenuated in an attenuator means 14. The combined signal output from the second subtractor 12 is fed to a second QGPA 11.

The second QGPA 11 is controlled via a first gain and filter means 40, which is supplied with Cartesian control signals I, Q from a first control means 16 according to an embodiment of the invention. The first control means 16 is supplied with Cartesian error signals I_e, Q_e from a pilot recovery and quadrature down conversion executed in a conversion means 18, said conversion means receiving the pilot tone from the pilot generator 5. An output signal from the second QGPA 11 is fed to an error power amplifier EPA 13 in which it is amplified and the resulting signal is fed to the first subtractor 8. The first subtractor 8 combines the two signals with which it has been supplied to produce a linearised output signal s_{out}. The second QGPA 11 together with the first control means 16 and its associated circuitry constitutes a loop, LOOP_2, of the feedforward lineariser. The loop LOOP_2 operates to reduce or cancel distortion.

The lineariser of fig 1 comprises two more loops, LOOP_1 for suppressing carriers from the MPA output signal, and LOOP_3 for suppressing carriers from the lineariser output signal s_{out}. In LOOP_1 (for suppressing carriers from the MPA output signal), the input signal s_{in}, delayed in the second delay means 10, is tapped before and after the second subtractor 12, using a first 20 and second 22 coupler respectively. These tapped signals are fed to a first complex Cartesian Correlator 24. The first complex Cartesian Correlator 24 produces Cartesian error signals which are supplied to a second control means 26 according to the invention. The second control means 26 generates Cartesian control signals for the control of the first QGPA 3. Said Cartesian control signals are fed to the first QGPA 3 via a second gain and filter means 42.

In LOOP_3 (for suppressing carriers from the lineariser output signal s_{out}), the delayed signal from the second delay means 10 is further delayed in a third delay means 28 and fed to a third QGPA 29. From the third QGPA 29, the signal is forwarded to a third subtractor 30 in which it is combined with a sample of the linearised output signal s_{out}. The thereby combined signal is fed to the conversion means 18 executing the pilot recovery and quadrature down conversion for generating error signals for the first control means 16 in the distortion cancellation loop, LOOP_2. The signal is tapped before and after the third subtractor 30 by a third 32 and fourth 34 coupler

respectively, and the tapped signals are fed to a second Cartesian Correlator 36. In the second Cartesian Correlator 36, control signals for a third control means 38 are generated. The third control means 38 is used to control the third QGPA 29 in LOOP_3 (for suppressing carriers from the lineariser output signal), and generates Cartesian control signals which are fed to the third QGPA 29 via a third gain and filter means 44.

Figure 2

Figures 2A, 2B, and 2C show three embodiments of a Cartesian control system including a supervisory control loop and a control means 16 according to an embodiment of the invention. Cartesian input and feedback signals are combined to form Cartesian error signals and, according to embodiments of the invention, either the Cartesian error signals or the Cartesian feedback signals are rotated by a phase shift ϕ so that phase-alignment is maintained between input and feedback signals. This rotation is controlled by a phase adjuster 52. Two sets of signals are tapped from the Cartesian control system and fed to the phase adjuster. Depending on where these two sets of signals are tapped, the phase parameter derived will be either a bulk phase shift between the tap points through the system to be controlled (Fig. 3), or a differential phase shift between the tap points through the system to be controlled and the phase rotator (Fig. 2).

In fig 2A, the control means 16 comprises a phase rotator 50 and a phase adjuster 52 comprising a phase parameter deriving means 252 and a phase adjusting means 352. Cartesian error signals I_e and Q_e are inserted into the phase rotator 50 wherein they are phase rotated. Here supplied by the subtraction 51, 53 of input signals I_i, Q_i and feedback signals I_f, Q_f, Cartesian error signals could also be supplied in some other way, (by for instance an equivalent of the conversion means 18 in fig 1), well known in the art. In fig 2A, the phase rotator 50 is controlled by an output signal ϕ of the phase adjuster 52. The phase rotated signals I_e' and Q_e' are fed to a gain and filter

means 54. The output signals from the gain and filter means 54 are fed to the phase adjuster 52 and to a system to be controlled 55. The output signals from the system to be controlled 55 constitute the Cartesian feedback signals I_f, Q_f. The system to be controlled 55, is here shown to have two outputs, but feedback signals could for instance be supplied on separate outputs.

Figs 2B and 2C show alternative ways of applying the control means 16 to the loop according to a second and a third embodiment of the invention, their function being in correspondence with that of fig 2A. In all the embodiments shown in fig 2, signals are tapped by sets of tapping means T1-T6 from around the system to be controlled such that the phase parameter deriving means 252 estimates the differential phase shift. In fig 2, the tapping means T1-T6 comprise tap points, but they could also comprise couplers 20,22,32,34 as in the embodiment shown in fig 1, the feedforward lineariser.

The phase rotator 50 is controlled by the phase adjuster 52, and implements the phase rotation of the Cartesian signals. According to the invention, the adaptive phase adjuster 52 corrects the phase shift ϕ used in the phase rotator 50, such that the Cartesian input and feedback signals remain phase-aligned.

The Operation of the Phase Adjuster 52

The phase adjuster 52 operates as follows: The phase parameter deriving means 252 calculates a phase parameter θ, using one of the algorithms illustrated below. The phase parameter θ is then used by the phase- adjusting means 352 to update the phase value ϕ. The phase value ϕ is delivered from the phase adjuster 52 to the phase rotator 50. The phase rotator 50 rotates the error signals I_e Q_e in accordance with the received phase value ϕ. This may be an iterative procedure. In the embodiments shown in Fig. 2 the update is achieved by one of the following formulas:

$$\phi_{(n+1)} = \phi_{(n)} + \theta \qquad (1)$$

or

$$\phi_{(n+1)} = \phi_{(n)} - \theta \qquad (2)$$

Whether the phase parameter θ should be added to the previous phase value $\phi_{(n)}$, or subtracted from the previous phase value $\phi_{(n)}$, is determined by the choice of tap points.
Hence an updated phase value $\phi_{(n+1)}$ is obtained in dependence on a previous phase value ϕ_n and the phase parameter θ.

The phase adjustment technique is, according to this embodiment, comprised in the phase adjuster 52. Said technique uses four input signals tapped from the Cartesian control loop (see fig 2), i.e. it is not obtrusive. No off-line calibration is therefore needed in a system according to the invention. Two signals that are tapped from before the gain and filter means 54 are referred to as the first tap signals, i and q (fig 2 shows possible locations from which these signals for instance can be tapped), and two signals tapped after the gain and filter means 54 are referred to as the second tap signals, I and Q. According to an embodiment of the invention, phase-alignment is maintained between Cartesian input signals and Cartesian feedback signals, using a phase rotation of either of said error or feedback signals based on a phase shift calculated between the two sets of signals tapped at two different locations in the Cartesian control loop.

The phase parameter deriving means 252 receives the four tapped signals i, q, I, Q, and generates four gradient signals, Δi, Δq, ΔI and ΔQ. These gradients are used to estimate a phase parameter θ. To further improve the phase parameter θ, the result can be integrated or averaged. The phase parameter θ is then, in this case (fig. 2), added to, or subtracted from, the current phase ϕ to generate the new phase value $\phi_{(n+1)}$, which subsequently is used to control the phase rotator 50. The system according to the invention derives the phase parameter θ non-obtrusively, regardless of the system state i.e. settled, converging, undergoing a transient or unstable.

Gradients of each of these signals i, q, I, Q, are first calculated. The generation of signal gradients in an analogue system, is well known to the man skilled in the art and

could be done for instance by a differentiator. In a digital system, this could for instance be done by subtracting the stored last value:

$$\Delta i = i(n) - i(n-1).$$

If the tapped signals have an origin near to zero, the gradient can be approximated by using the current value: $\Delta i = i(n)$.

These gradient signals are then used to estimate the phase parameter θ in the Cartesian control system. According to embodiments of the invention, the phase parameter θ is generated in dependence from the four gradient signals.

According to one embodiment the phase parameter θ is calculated as (technique 1):

$$\theta = \tan^{-1}\theta_2 \qquad (3)$$

where

$$\theta_2 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\Delta q \times \Delta Q + \Delta i \times \Delta I} \qquad (4)$$

According to another embodiment, referred as a second technique, the phase parameter θ is calculated as follows (technique 2):

$$\theta = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\Delta q \times \Delta Q + \Delta i \times \Delta I} \qquad (5)$$

Equation (5) provides an approximation of equation (3).

According to yet another embodiment the phase parameter θ is calculated as follows (technique 3):

$$\theta = \sin^{-1}\theta_4 \qquad (6)$$

where

$$\theta_4 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\sqrt{\left(\Delta q^2 + \Delta i^2\right)\left(\Delta Q^2 + \Delta I^2\right)}} \qquad (7)$$

According to another embodiment (technique 4) the phase parameter θ is calculated as an approximation of technique 3:

$$\theta = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\sqrt{\left(\Delta q^2 + \Delta i^2\right)\left(\Delta Q^2 + \Delta I^2\right)}} \qquad (8)$$

According to yet another embodiment the phase parameter θ is calculated as follows (technique 5):

$$\theta = \Delta q \times \Delta I - \Delta i \times \Delta Q \qquad (9)$$

Equation (9) is a simplification of all above techniques, using numerator only.

In all of the above equations (3) to (9) the phase parameter θ is expressed as radians. Techniques 1 and 3 are linear phase detector functions and can be used to generate a phase parameter. Techniques 2 and 4 are approximations of techniques 1 and 3 respectively. They generate an approximation of the absolute phase parameter, and can also be used with some restrictions as to the denominator being zero. Technique 5 is basically a non-linear phase detector function.

The phase parameter θ as calculated from one of the equations, may also require correction before being used by the phase adjusting means 352. For example, intervention may be required on the detection of certain boundary conditions, such as saturation of the tap signals etc.

A correct interpretation of what quadrant the phase parameter θ falls into must also be taken into account when using the equations. For example in technique 1 and 2, all four quadrants can be correctly resolved provided the numerator and denominator are examined. In technique 3, 4 and 5 only two quadrants can be correctly resolved since the denominator is always positive.

tan(-1/1) => θ = +135° in second quadrant

tan(1/-1) => θ = -45° in fourth quadrant.

The phase adjustment means then uses the phase parameter θ to update the phase ϕ. For example in a situation where the tap points generate a differential phase estimate (Figs. 1, 2 & 5), then a scaled quantity of the phase parameter θ can be added to the current phase:

$$\phi(n+1) = \phi(n) + k\theta;$$

where k is a scaling factor. It may be necessary to scale the phase parameter θ to ensure stability around the phase aligning loop. Another possibility is to take the sign of the phase estimate which determines the direction in which to change the phase ϕ, and then use k as a scaling factor that gives the size of this change.

$$\phi(n+1) = \phi(n) + k\,\mathrm{sgn}(\theta);$$

where $\mathrm{sgn}(\theta) = 1$ for $\theta >= 0$

$\mathrm{sgn}(\theta) = -1$ for $\theta < 0$

The estimate of the phase parameter θ can also be improved by integration (averaging), before being used by the phase adjusting means 352, as according to this embodiment of the invention.

The phase adjuster techniques according to the invention continue to operate regardless of whether the feedback loop has settled, is converging, is undergoing a transient situation or is presently unstable (a temporary state as eventually the phase is corrected and the system returns to stability).

The Phase Rotator 50

The phase rotator 50 according to an embodiment of the invention comprises a device for performing a complex multiplication and referring to Fig. 2A performs the operation expressed by the following equations:

$$I_e' = I_e\cos\phi - Q_e\sin\phi$$

$$Q_e' = I_e\sin\phi + Q_e\cos\phi$$

The phase rotator 50 could alternatively comprise an approximation of said equations.

The gain and filter means 54 comprise a gain and a low pass filtering function. Other ways of filtering well known in the art could also be used. Together with the analogue circuitry, they govern the time constant (speed or bandwidth) of the control system.

Figure 3

Fig 3 shows three more ways of applying a control means according to the invention to a feedback loop. Figs 3A, 3B and 3C show a control means 103, 113, 123 according to a fourth, fifth and sixth embodiment of the invention respectively.

In these embodiments of the invention the phase rotator 50 is controlled by a phase adjuster 102 and implements the phase rotation of the Cartesian signals. According to an embodiment of the invention, the adaptive phase adjuster 102 corrects the phase shift ϕ used in the phase rotator 50 such that the Cartesian input and feedback signals remain phase-aligned.

The phase adjuster 102 corresponds to the phase adjuster 52, but it differs in that phase value adjusting means 552 operates slightly differently from the above described phase adjusting means 352.

The phase parameter deriving means 252 calculates a phase parameter θ, through either one of the algorithms described above, or an approximation thereof . In the context of the embodiments shown in Fig. 3, the following conditions apply to phase parameter deriving means 252. When technique 1 (eq. 3) is used, no restrictions apply.
Technique 2 (eq. 5) works well when θ is in the range from -45° to +45 °. Technique 2 (eq. 5) also works well when θ is in the range from 135 ° to 225°.
Technique 3 (eq. 6) works in quadrants 1 and 4, i.e. $-90° < \theta < 90°$.
Technique 4 (eq. 8) works well when θ is in the range from -45° to +45°.
Technique 5 (eq. 9) also works well when θ is in the range from -45° to +45°.
The angular values are presented in degrees in this text for the purpose of simplifying the understanding. The calculations, however should be made with radians. The

parameter value obtained by equation (5) is expressed in radians. Likewise the parameter value obtained by equations (8) and (9) is expressed in radians.

In the embodiments shown in Fig. 3 the update of the phase value ϕ is achieved by one of the following formulas:

$$\phi_{(n+1)} = + \theta$$

or

$$\phi_{(n+1)} = - \theta$$

Whether the phase value $\phi_{(n+1)}$ should be set to $+ \theta$ or to $- \theta$ is determined by the choice of tap points.

The phase adjustment technique is, according to this embodiment of the invention, comprised in the phase adjuster 102. Said technique uses four input signals tapped from the Cartesian control signal paths, i.e. it is not obtrusive. No off-line calibration is therefore needed in a system according to the invention. Two signals, i and q are tapped (Fig. 3 shows possible locations, T7, T9, T12 from which these signals for instance can be tapped), and another two signals are tapped, I and Q from locations T8, T10, T11. According to the invention, phase-alignment is maintained between Cartesian input signals and Cartesian feedback signals, using a phase rotation of either of said error or feedback signals based on a phase shift calculated between the two sets of signals tapped at two different locations.

The four tapped signals are used to generate four gradient signals, Δi , Δq, ΔI and ΔQ. These gradients are used to estimate a phase parameter θ. To further improve the phase parameter θ, the result can be integrated or averaged. The new phase value $\phi_{(n+1)}$ is set equal to the value of the estimated phase parameter θ, according to the embodiments described in connection with Fig.3. The new phase value $\phi_{(n+1)}$ is subsequently used for controlling the phase rotator 50. The system according to the invention derives the phase parameter θ non-obtrusively, regardless of the system state, i.e. regardless of whether the system is settled, converging, undergoing a transient or unstable.

The estimated phase parameter θ, which is generated by the phase parameter deriving means 252, may also require correction before being used by the phase adjusting means 552. For example, intervention also be required on the detection of certain boundary conditions, such as saturation of the tap signals etc.

A correct interpretation of what quadrant the phase parameter θ falls into must also be taken into account when using the equations, as previously discussed.

The estimate of the phase parameter θ can be improved by integration (averaging), before being used by the phase adjusting means 552, as according to this embodiment of the invention.

According to the embodiments shown in Fig. 2 and 3, a supervisory control loop operates to monitor the phase shift in at least one of the components in the main control loop of the feedback control system. The supervisory control loop includes a phase parameter generator 252, a phase value generator 352,552, a phase rotator 50, and at least one component in the main control loop of the Cartesian control system.

Figure 4

Fig 4 shows a flow chart of a method of phase adjustment comprised in the phase adjuster 52,102 according to an embodiment the invention. Signals tapped at the first and second tap points are input, in step 400, to the phase adjuster 52 or 102.

The phase deriving means 252 comprised in the phase adjuster 52 or 102 estimates a phase parameter θ in step 402, using one of the equations given above, or an approximation of one of the equations given above.

If necessary, the phase parameter θ is corrected in step 404, and the corrected phase parameter $\hat{\theta}$ is then used by the phase adjusting means 352,552, also comprised in the

phase adjuster 52 or 102, to adjust, in step 406, the phase value ϕ which is output, in step 408, from the phase adjuster 52 and fed to the phase rotator 50 where it is used to rotate the Cartesian signals.

The phase rotator 50 operates to receive a Cartesian signal pair and to receive the phase value from the phase adjuster 52. The phase rotator 50 operates to rotate the Cartesian signals by an angle corresponding to the phase value ϕ.

The corrected estimate of the phase parameter $\hat{\theta}$ can be improved by integration (averaging) in an additional step, not shown in fig. 4, before being used by the phase adjusting means 352 or 552.

A Digital System including a Digital Signal Processor

As mentioned above, the method according to the invention may be implemented in a digital system. According to one embodiment of the invention the controller 16 comprises a digital signal processing device 560, a non-volatile memory 564 and a volatile memory (Fig. 7). The non-volatile memory 564 stores a computer program including computer readable code for controlling the digital signal processor to operate in accordance with a method described with reference to Fig. 4 in conjunction with Figures 2 or 3 above. The non-volatile memory 564 is coupled to the digital signal processor 560 via a data bus 566. The digital signal processing device 560 may include one, two or several digital signal processors 560A, 560B for performing the functions described below. The computer program may be provided on a different carrier, such as a compact disc, and it can be installed on the non-volatile memory 564 via a data bus. The computer program The controller shown in Fig. 7 is suitable to be connected in a Cartesian control system as described in Fig. 2 above. Although the digital signal processing device 560 and its function is described with reference to Figure 2 and 7 it is to be understood that it may be used with other embodiments of Cartesian control systems as well.

The phase adjuster 52, or 102 receives the first signal pair i, q and the second signal pair I, Q. The program routine recorded in the non-volatile memory causes the digital signal processor 560B to generate a differential value Δq, e.g. by temporarily storing consecutive values q(n-1), q(n) of the q-signal and then subtracting a previous value q(n-1) from the subsequent value q(n):

$$\Delta q = q(n) - q(n-1)$$

Differential values Δi, Δq, ΔI, ΔQ for each of the four signals i, q , I, Q are generated in the same manner.

A phase parameter θ is generated in dependence of the differential values Δi, Δq, ΔI, ΔQ. In this step the digital signal processor 560B executes calculations in accordance with the equations (3) - (9), described above.

Thereafter program routine causes the digital signal processor to generate a phase value ϕ in dependence on the phase parameter θ. The phase value ϕ functions as a reference value in the process of phase rotation.

The Cartesian signal pair I, Q to be rotated is received by the controller 16, 103 113, 123. In the embodiment illustrated in Fig. 7, the signal pair I, Q to be rotated is received by processor 560A. The program routine causes the digital signal processor 560A to generate a pair of rotated Cartesian signals I', Q' in response to the phase value ϕ and the received signal pair I, Q. The rotation procedure may include performing a multiplication given by the following equations (referring to Fig. 2A):

$$I_e' = I_e\cos\phi - Q_e\sin\phi$$

$$Q_e' = I_e\sin\phi + Q_e\cos\phi$$

The program routine causes the digital signal processor to perform the above steps iteratively.

In the above described embodiment the digital signal processor 560B generates a phase parameter, the numerical value of which is actually used for controlling the phase

value ϕ. According to another embodiment of the invention the program routine causes the digital signal processor to analyze the sign, positive or negative, of the phase parameter θ obtained using an approximation of equation (3) in combination with eq. (4). Alternatively an approximation of equation (6) in combination with eq. (7) is used. Examples of such approximations are given by equations (5) and (8), respectively, as well as by equation (9). The calculations are simplified by using approximations. According to a preferred version of this embodiment equation (9) is used. The simplified calculations render an advantageously quick and efficient digital processing of the data. Moreover, since the simplified calculations render an increased data processing rate it also renders a very efficient control.

The sign, positive or negative, of the phase parameter θ indicates whether the phase value ϕ needs to be increased or decreased. The program routine causes the digital signal processor to change the numerical value of the phase value ϕ in response to the sign of the phase parameter θ. Thereafter the program routine causes the digital signal processor 560A to generate a pair of rotated Cartesian signals I', Q' in response to the phase value ϕ and the received signal pair I, Q, as described above. These steps are iterated or repeated so as to maintain the phase parameter value at zero, or at a value near zero.

A scaling factor k may be used for determining how much to change the phase value in one iteration of the above described method.

$$\phi(n+1) = \phi(n) + k\,\mathrm{sgn}(\theta); \qquad \mathrm{sgn}(\theta) = 1 \text{ for } \theta >= 0$$

$$\mathrm{sgn}(\theta) = -1 \text{ for } \theta < 0$$

The embodiment of the controller as shown in Figure 7 may also be used for performing the embodiment of the method described above with reference to Figure 6.

Figure 5

Fig 5 shows an embodiment of a controller 62 according to the invention, applied to a Cartesian feedback transmitter, according to yet another embodiment of the invention. The controller 62 may be a controller 52 for performing the steps described with reference to Fig. 2A. Cartesian input signals I_{in}, Q_{in} and Cartesian feedback signals I, Q are combined in a first and second sub-tractor 140, 142. The combined signals are fed to respective gain and filter means 144, 146 the output signals i, q of which are fed to a quadrature modulator 148. The modulator output signal is amplified in a power amplifier 150 and forwarded to an antenna 152. Error signals being the output signals i, q of the gain and filter means 144, 146 are fed to a phase adjuster 62. The amplified modulator output signal is tapped using a coupler 154 and fed to a quadrature demodulator 156 wherein it is demodulated into said Cartesian feedback signals I, Q, which are fed to the subtractors 140, 142 as well as to the phase adjuster 62. Based on the signals input to the phase adjuster, a phase parameter is estimated according to the invention, and said phase estimate is used to control a phase rotator 60, such that the signal from the Local Oscillator 160 arriving at the modulator 148 via a splitter 161 and the phase rotator 60, and at the demodulator 156 via the splitter 161, causes the input signals i, q and the feedback signals I, Q to be phase-aligned or substantially phase-aligned.

With reference to Fig. 5, a main control loop of the transmitter is defined by the signal path including subtractors 140, 142, the gain and filter means 144, 146, quadrature modulator 148, the power amplifier 150, the coupler 154 and via the quadrature de-modulator 156 back to the subtractors 140, 142. In such a control loop it is important that the feedback signals I, Q which are delivered to the subtractors 140, 142 are phase aligned with the Cartesian input signals I_{in}, Q_{in}.

Let us consider an extreme example for the purpose of simplifying the understanding of the logic behind the invention: If, for example, the feedback signals I, Q were phase shifted by 180 degrees in relation to the input signals I_{in}, Q_{in}: then the polarity of the feedback signals would be such that the subtractors 140,142 actually cause an addition rather than a subtraction. It is clear to any person skilled in the art that a system like

that would be totally unstable. It is, in fact preferable to keep the feedback signals I, Q phase aligned with the Cartesian input signals I_{in}, Q_{in}, i.e. the phase deviation is preferably kept to zero, to ensure that the subtractors 140, 142, respectively cause a subtraction.

According to the embodiment of the invention shown in Fig. 5 there is provided a supervisory phase alignment control loop, which is defined by the signal path including quadrature modulator 148, power amplifier 150, coupler 154, quadrature demodulator 156, phase adjuster 62, and via phase rotator 60 back to the quadrature modulator 148.

A first signal pair i, q are tapped from the forward path of the main control loop, and a second signal pair I, Q are tapped from the feedback path of the main control loop. The phase adjuster 62, which is positioned in the supervisory phase alignment control loop, continuously or repeatedly receives the first signal pair i, q as well as the second signal pair I, Q. In response to the first and second signal pairs the phase adjuster 62 in combination with the phase rotator 60 operates to reduce or eliminate any phase deviation in the main control loop. The continuous reduction or elimination of any phase deviation in the main control loop ensures a stable negative feedback in the main control loop.

Claims

1. A control means in a Cartesian control system having a control loop with Cartesian input signals and Cartesian feedback signals,
the control means (16, 26, 38, 103, 113, 123) comprising

- a phase rotator (50) for implementing a phase rotation of Cartesian signals;
- a phase adjuster (52, 102) having means (252) for deriving at least one phase parameter (θ) using signals (i, q, I, Q) tapped from the control loop, for controlling said phase rotator (50) such that the Cartesian input signals and the Cartesian feedback signals are maintained substantially phase-aligned.

2. A control means (16) according to claim 1, wherein

said phase parameter deriving means (252) operates to differentiate the signals (i, q, I, Q) tapped from the control loop so as to obtain a set of differential values (Δi, Δq, ΔI, ΔQ); and

said phase parameter deriving means (252) operates to generate the phase parameter value in response to said set of differential values (Δi, Δq, ΔI, ΔQ).

3. A control means (16) according to claim 1 or 2, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_1 = \tan^{-1}\theta_2; \qquad \text{where} \qquad \theta_2 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\Delta q \times \Delta Q + \Delta i \times \Delta I}$$

4. A control means (16) according to claim 1 or 2, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_2 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\Delta q \times \Delta Q + \Delta i \times \Delta I}.$$

5. A control means (16) according to claim 1 or 2, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_3 = \sin^{-1}\theta_4; \text{ where } \quad \theta_4 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\sqrt{\left(\Delta q^2 + \Delta i^2\right)\left(\Delta Q^2 + \Delta I^2\right)}}.$$

6. A control means (16) according to claim 1 or 2, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_4 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\sqrt{\left(\Delta q^2 + \Delta i^2\right)\left(\Delta Q^2 + \Delta I^2\right)}}.$$

7. A control means (16) according to claim 1 or 2, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_5 = \Delta q \times \Delta I - \Delta i \times \Delta Q .$$

8. A control means (16) according to any of the preceding claims, comprised in at least one of the Cartesian control systems within a feedforward lineariser.

9. A control method for linear Cartesian feedback control, wherein Cartesian input signals and Cartesian feedback signals are combined to form Cartesian error signals, the method comprising:

- deriving at least one phase parameter using signals tapped from the feedback loop;
- phase rotating signals within the Cartesian loop using said phase parameter;

thereby maintaining phase-alignment between the Cartesian input signals and said Cartesian feedback signals.

10. A control method according to claim 9, wherein said phase parameters are derived non-obtrusively to the control system operation.

11. A control method according to claim 9 or 10, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_1 = \tan^{-1}\theta_2 \text{ ; where } \qquad \theta_2 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\Delta q \times \Delta Q + \Delta i \times \Delta I}.$$

12. A control method according to claim 9 or 10, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_2 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\Delta q \times \Delta Q + \Delta i \times \Delta I}.$$

13. A control method according to claim 9 or 10, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_3 = \sin^{-1}\theta_4; \text{ where } \qquad \theta_4 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\sqrt{\left(\Delta q^2 + \Delta i^2\right)\left(\Delta Q^2 + \Delta I^2\right)}}.$$

14. A control method according to claim 9 or 10, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_4 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\sqrt{\left(\Delta q^2 + \Delta i^2\right)\left(\Delta Q^2 + \Delta I^2\right)}}.$$

15. A control method according to claim 9 or 10, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_5 = \Delta q \times \Delta I - \Delta i \times \Delta Q.$$

16. A control method according to any of the preceding claims, controlling at least one of the Cartesian control systems within a feedforward lineariser.

17. A Cartesian control system having Cartesian input signals (I_{in}, Q_{in}) and Cartesian feedback signals (I_f, Q_f), comprising:

- a first and a second subtractor (51,53) for subtracting the Cartesian feedback signals from the Cartesian input signals, thereby forming Cartesian error signals (I_e, Q_e);
- a phase rotator (50) for implementing a phase rotation of the Cartesian error signals (I_e, Q_e) or feedback signals (I_f, Q_f);
- a gain and filter means (54) for amplifying said phase rotated Cartesian signals;
- a first and a second set of tapping means (T1, T2) for tapping signals (i, q, I, Q) from the Cartesian control loop;
- a phase adjuster (52), deriving at least one phase parameter using said tapped signals (i, q, I, Q), for controlling said phase rotator (50);
- a system to be controlled (55);

wherein phase-alignment is maintained between the Cartesian input signals (I_i, Q_i) and said Cartesian feedback signals (I_f, Q_f).

18. A Cartesian control system according to claim 17, wherein said deriving of phase parameters is non-obtrusive to the control system operation.

19. A method for Cartesian feedback control, comprising:

- combining Cartesian feedback signals (I_f, Q_f) and Cartesian input signals (I_i, Q_i) to form Cartesian error signals (I_e, Q_e);
- tapping two sets of signals (i, q, I, Q) from a Cartesian control loop;
- phase rotating said Cartesian error signals (I_e, Q_e) or said feedback signals (I_f,Q_f);
- amplifying said phase rotated Cartesian error signals (I_e, Q_e) or feedback signals (I_f,Q_f);
- deriving at least one phase parameter using said signals (i, q, I, Q) tapped from the Cartesian control loop;
- adjusting said phase rotation using said phase parameters;
- filtering said amplified, phase rotated Cartesian signals;

- providing Cartesian control signals from said filtered amplified phase rotated Cartesian signals;

whereby phase-alignment is maintained between said Cartesian input signals (I_i, Q_i) and said Cartesian feedback signals (I_f, Q_f).

20. A method for Cartesian loop feedback control according to claim 19, wherein said phase parameters are derived non-obtrusively to the control system operation.

21. A phase adjuster (52) in a Cartesian control system, comprising:

- phase parameter deriving means (252) for deriving at least one phase parameter from sets of Cartesian signals;
- phase adjusting means (352) for adjusting said at least one phase parameter;

thereby maintaining phase-alignment between said Cartesian signals.

22. A phase adjuster according to claim 21, which is non-obtrusive to normal system operation.

23. A phase adjuster according to claim 21 or 22, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_1 = \tan^{-1}\theta_2; \text{ where } \quad \theta_2 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\Delta q \times \Delta Q + \Delta i \times \Delta I}$$

24. A phase adjuster according to claim 21 or 22, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_2 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\Delta q \times \Delta Q + \Delta i \times \Delta I}.$$

25. A phase adjuster according to claim 21 or 22, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_3 = \sin^{-1}\theta_4; \text{ where } \quad \theta_4 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\sqrt{\left(\Delta q^2 + \Delta i^2\right)\left(\Delta Q^2 + \Delta I^2\right)}}.$$

26. A phase adjuster according to claim 21 or 22, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_4 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\sqrt{\left(\Delta q^2 + \Delta i^2\right)\left(\Delta Q^2 + \Delta I^2\right)}}.$$

27. A phase adjuster according to claim 21 or 22, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_5 = \Delta q \times \Delta I - \Delta i \times \Delta Q .$$

28. A phase adjuster according to any of the preceding claims, comprised in at least one of the Cartesian control systems within a feedforward lineariser.

29. A method for phase adjustment in a Cartesian control system, the method comprising:

- obtaining sets of Cartesian signals;
- deriving at least one phase parameter using said signals;
- adjusting a phase of at least one of said sets of Cartesian signals in relation to said at least one phase parameter such that phase deviations between said sets of Cartesian signals are minimized.

30. A method according to claim 29, which is non-obtrusive to the control system operation.

31. A method according to claim 29 or 30, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_1 = \tan^{-1}\theta_2 \text{; where} \qquad \theta_2 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\Delta q \times \Delta Q + \Delta i \times \Delta I}$$

32. A method according to claim 29 or 30, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_2 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\Delta q \times \Delta Q + \Delta i \times \Delta I}.$$

33. A method according to claim 29 or 30, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_3 = \sin^{-1}\theta_4; \text{ where } \quad \theta_4 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\sqrt{\left(\Delta q^2 + \Delta i^2\right)\left(\Delta Q^2 + \Delta I^2\right)}}.$$

34. A method according to claim 29 or 30, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_4 = \frac{\Delta q \times \Delta I - \Delta i \times \Delta Q}{\sqrt{\left(\Delta q^2 + \Delta i^2\right)\left(\Delta Q^2 + \Delta I^2\right)}}.$$

35. A method according to claim 29 or 30, wherein said phase parameter is obtained through the equivalent to, or an approximation of, the equation:

$$\theta_5 = \Delta q \times \Delta I - \Delta i \times \Delta Q.$$

36. A control method according to any of the preceding claims, controlling at least one of the Cartesian control system within a feedforward lineariser.

37. A method of compensating a phase rotation in a control loop of a cartesian control system;

the method comprising the steps of:

receiving a first signal pair (i, q), whose signal values originate from a first location in the control loop;

receiving a second signal pair (I, Q), whose signal values originate from a second location in the control loop;

estimating a phase difference (θ) between the first signal pair (i, q) and the second signal pair (I, Q), said difference being indicative of a phase rotation (θ) in the control loop;

generating a reference value ($\phi_{(n)}$; ϕ) in dependence on said phase rotation estimate (θ);

causing a phase rotation in the control loop in accordance with the reference value ($\phi_{(n)}$; ϕ) so as to compensate for said phase rotation (θ).

38. The method according to claim 37; wherein

the estimation step includes:

differentiating the signals of said first signal pair (i, q), and differentiating the signals of said second signal pair (I, Q) so as to generate a set of differentiated signal values (Δi, Δq, ΔI, ΔQ);

generating said phase estimate (θ) in dependence on said differentiated signal values (Δi, Δq, ΔI, ΔQ).

39. The method according to claim 37 or 38; wherein

the step of generating a reference value ($\phi_{(n)}$; ϕ) includes:

retrieving a previous reference value ($\phi_{(n)}$);

generating an updated reference value ($\phi_{(n+1)}$) by increasing the numerical value of the previous reference value ($\phi_{(n)}$) if the phase estimate has a first sign, or by decreasing the numerical value of the reference value ($\phi_{(n)}$) if the phase estimate has a second sign.

40. The method according to any of claims 37 - 49, wherein

the method steps according to any of claims 37 - 49 are repeated.

41. A computer program product for use with a Cartesian control system including a control loop and a digital processing device (560);

the computer program product comprising:

a recording medium (564); and

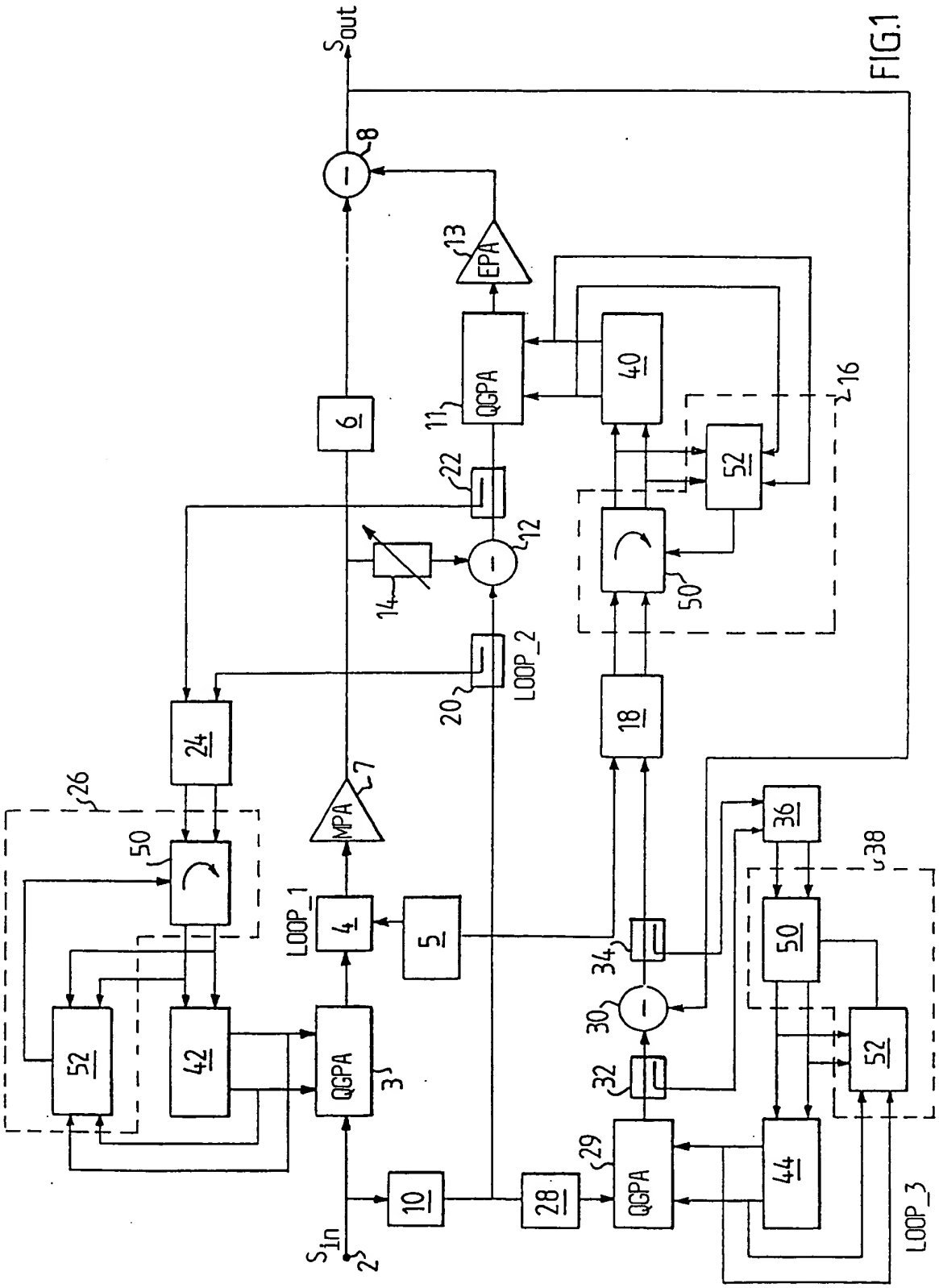
computer readable code means, recorded on the recording medium, for directing the digital processing device (560) to receive a first signal pair (i, q);

computer readable code means, recorded on the recording medium, for directing the digital processing device (560) to receive a second signal pair (I, Q);

computer readable code means, recorded on the recording medium, for directing the digital processing device (560) to estimate a phase difference (θ) between the first signal pair (i, q) and the second signal pair (I, Q), said difference being indicative of a phase rotation (θ) in the control loop;

computer readable code means, recorded on the recording medium, for directing the digital processing device (560) to generate a reference value ($\phi_{(n)}$; ϕ) in dependence on said phase rotation estimate (θ);

computer readable code means, recorded on the recording medium, for directing the digital processing device (560) to cause a phase rotation in the control loop in accordance with the reference value ($\phi_{(n)}$; ϕ) so as to compensate for said phase rotation (θ).



SUBSTITUTE SHEET (RULE 26)

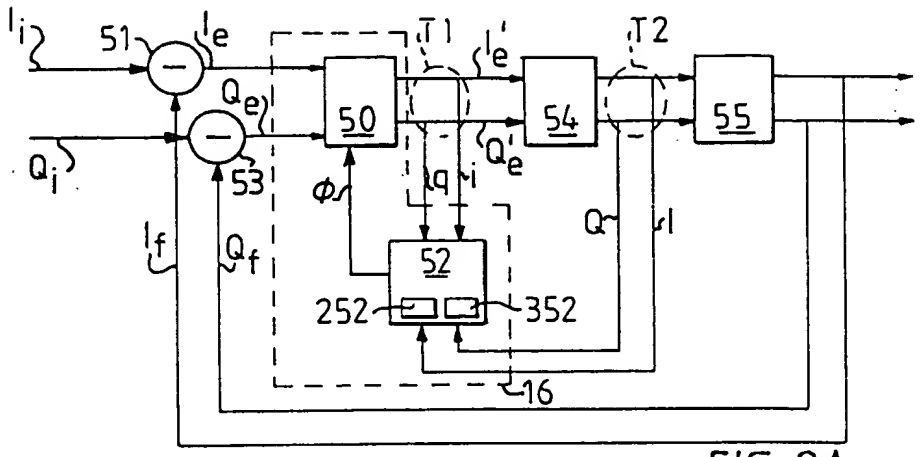


FIG. 2A

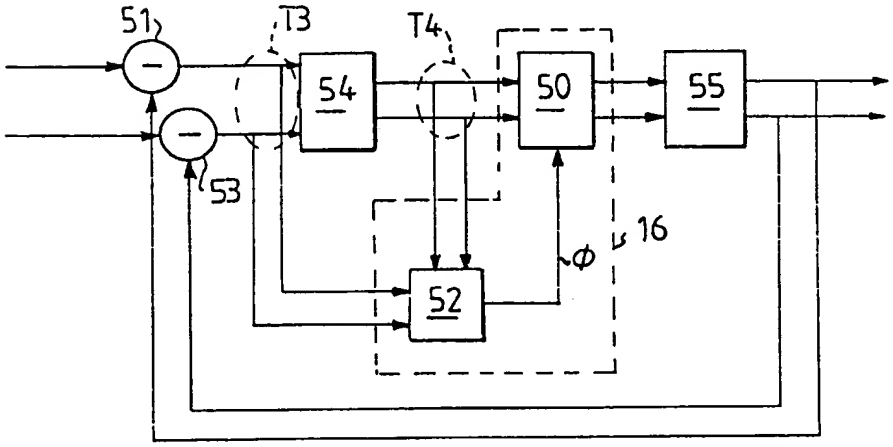


FIG.2B

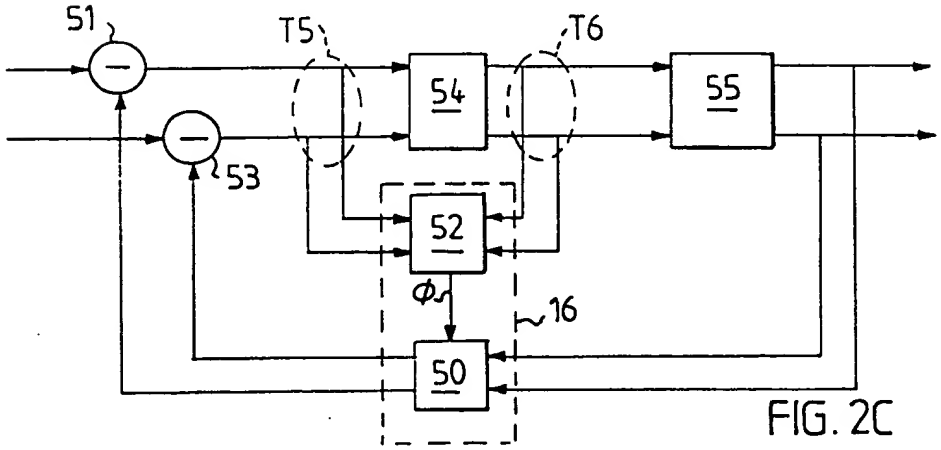


FIG. 2C

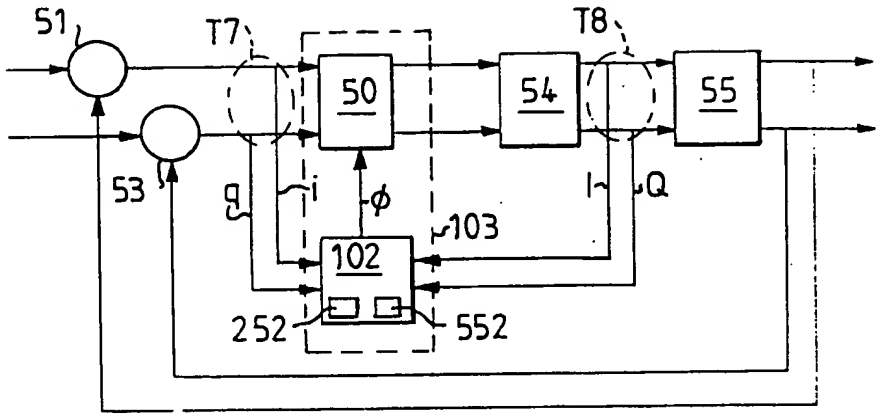


FIG. 3A

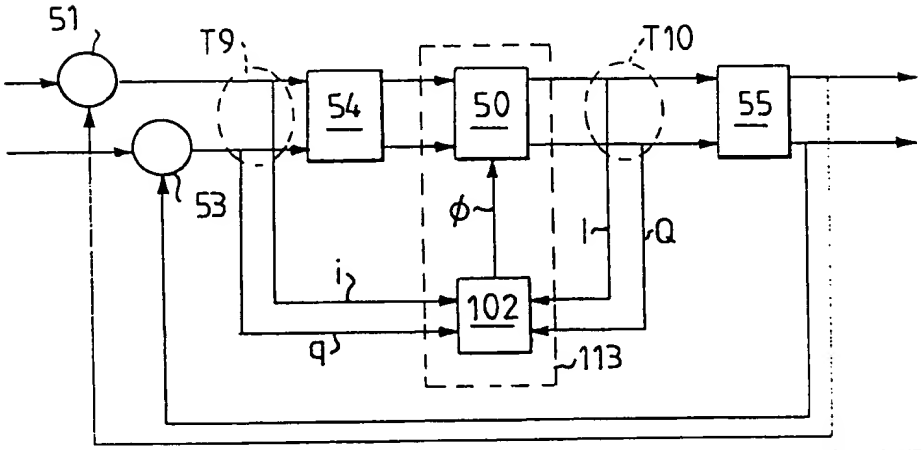


FIG. 3B

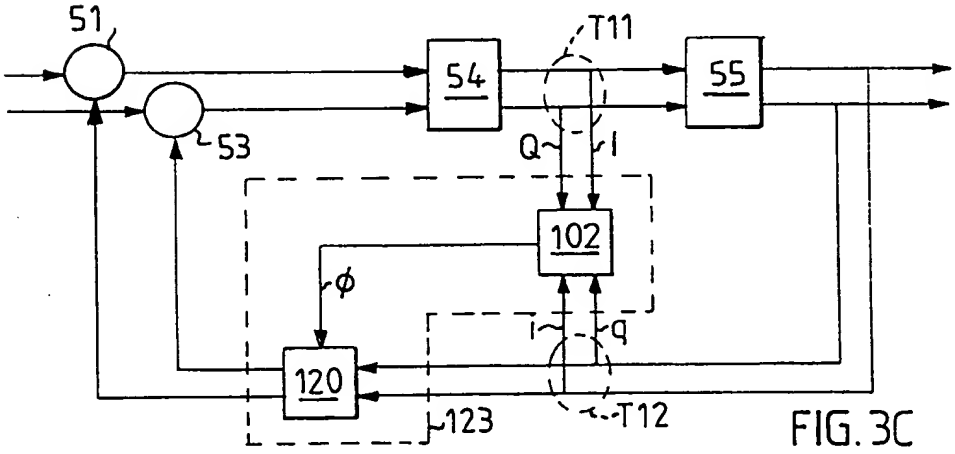


FIG. 3C

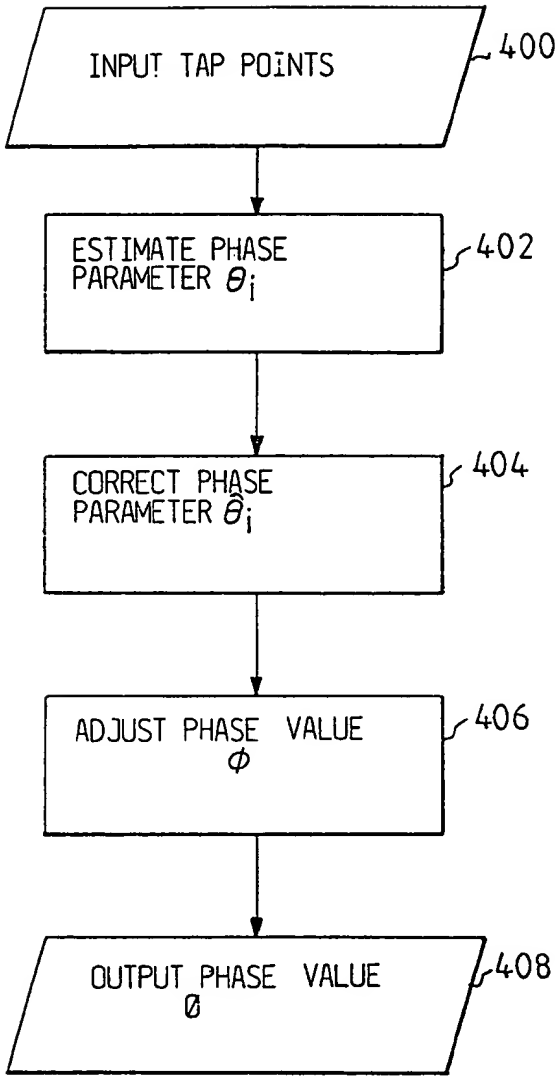

INPUT TAP POINTS
400
ESTIMATE PHASE PARAMETER θ_i
402
CORRECT PHASE PARAMETER $\hat{\theta}_i$
404
ADJUST PHASE VALUE ϕ
406
OUTPUT PHASE VALUE $\emptyset$
408

FIG.4

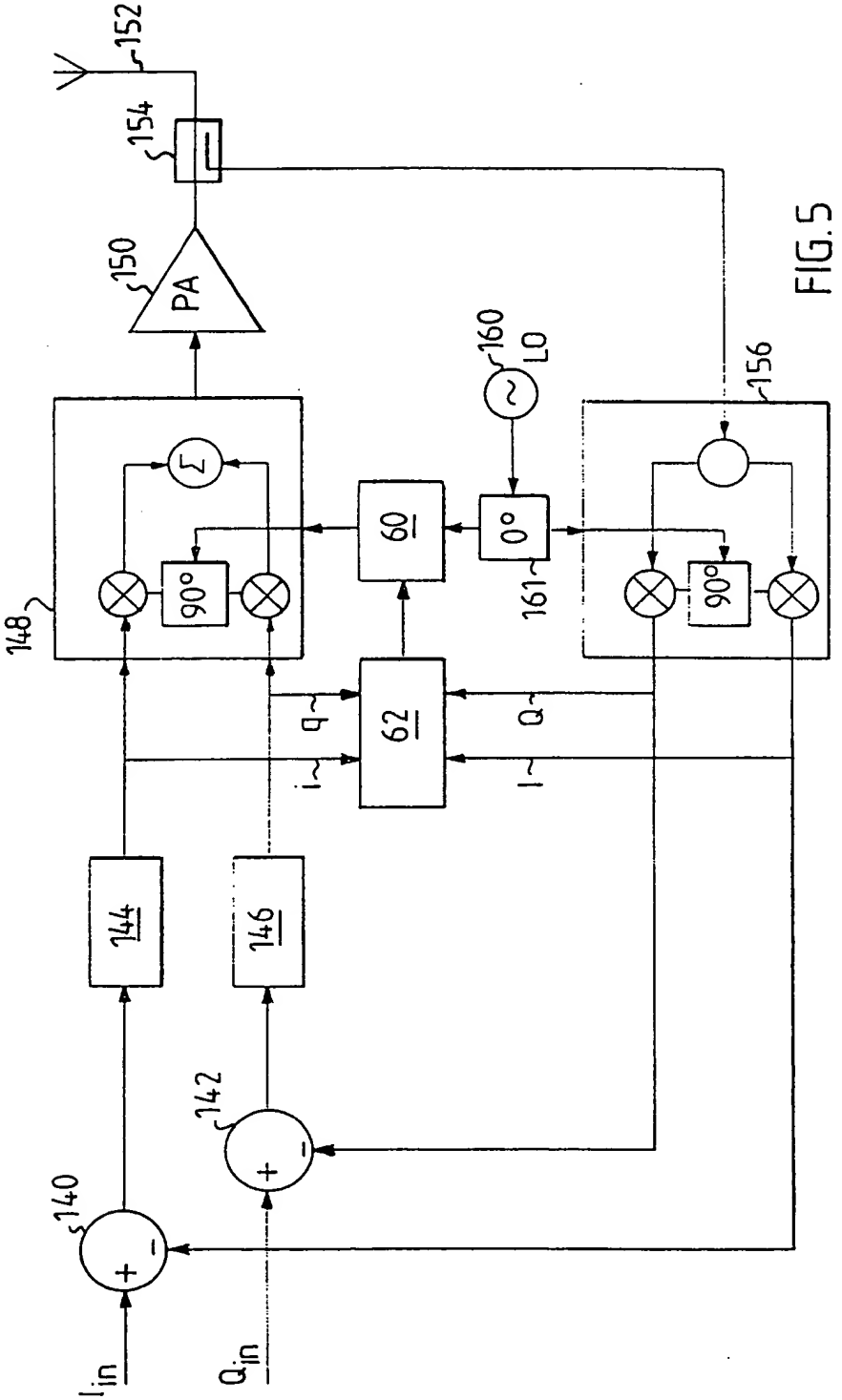

152
154
150
PA
160
LO
156
148
90°
60
0°
161
90°
62
144
146
142
140
I_{in}
Q_{in}

FIG.5

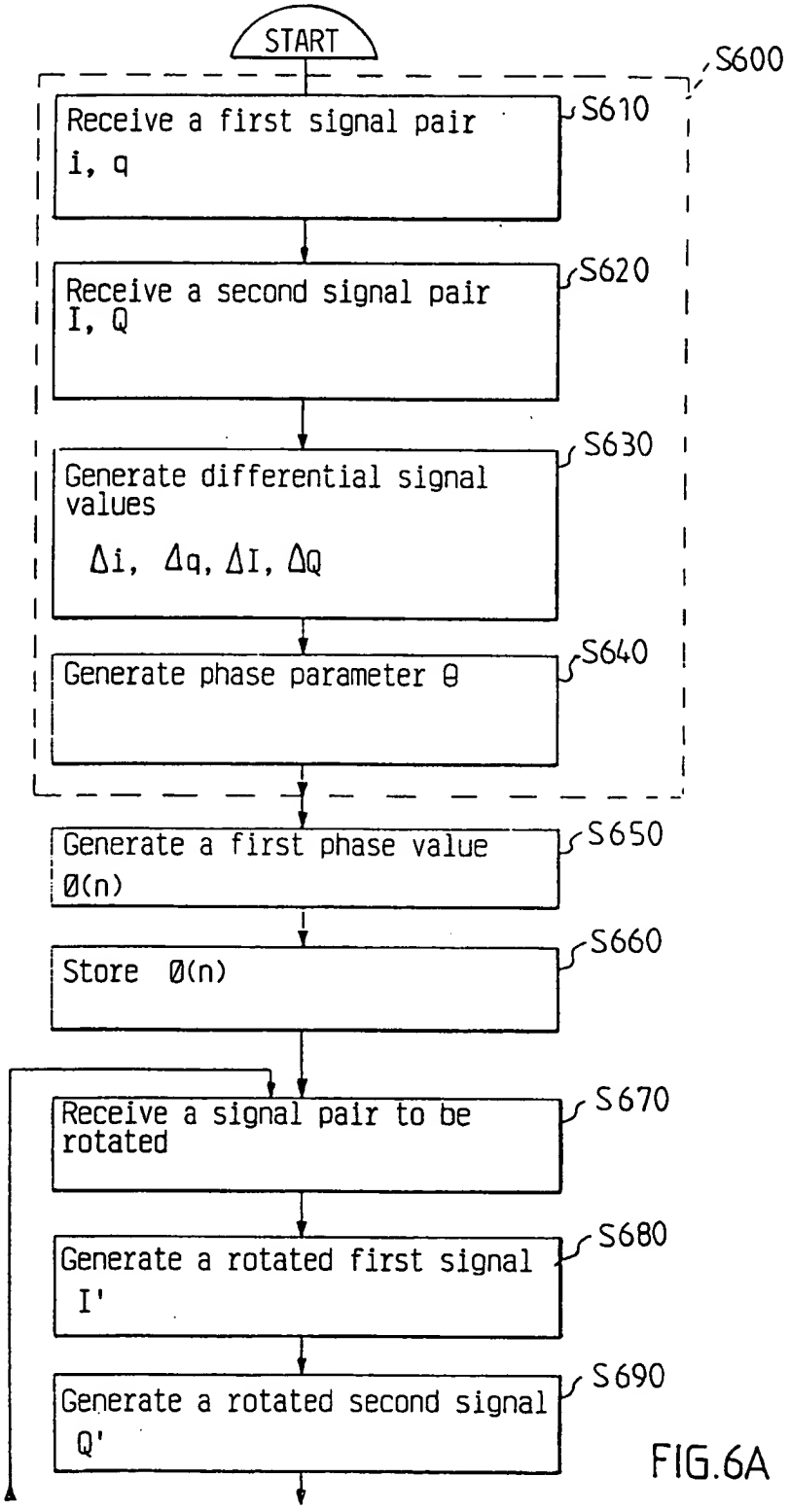

START
S600
Receive a first signal pair
i, q
S610
Receive a second signal pair
I, Q
S620
Generate differential signal values
Δi, Δq, ΔI, ΔQ
S630
Generate phase parameter θ
S640
Generate a first phase value
Ø(n)
S650
Store Ø(n)
S660
Receive a signal pair to be rotated
S670
Generate a rotated first signal
I'
S680
Generate a rotated second signal
Q'
S690

FIG.6A

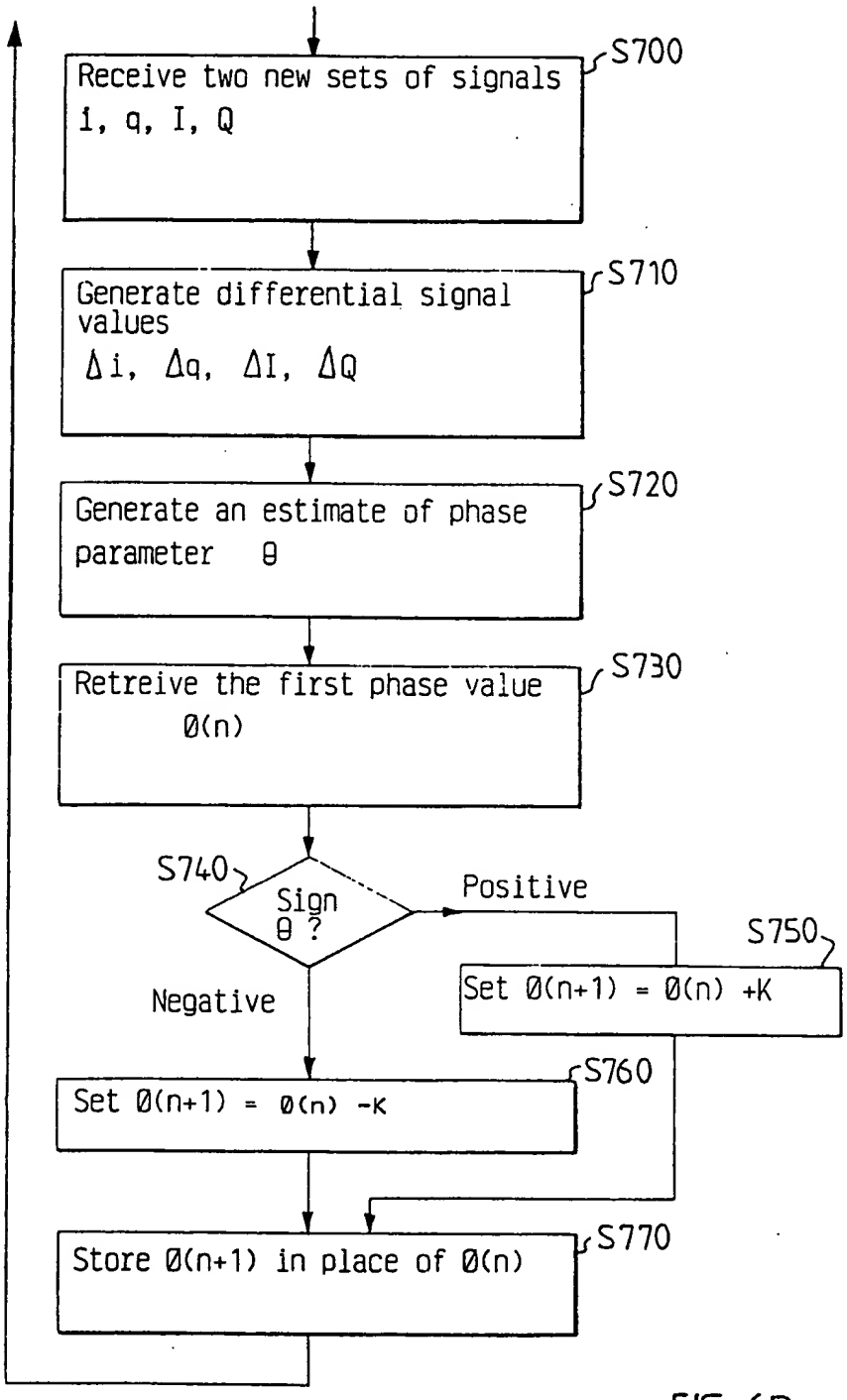

Receive two new sets of signals
i, q, I, Q
S700
Generate differential signal values
Δi, Δq, ΔI, ΔQ
S710
Generate an estimate of phase parameter θ
S720
Retreive the first phase value
Ø(n)
S730
S740
Sign θ ?
Positive
S750
Set Ø(n+1) = Ø(n) +K
Negative
S760
Set Ø(n+1) = Ø(n) -K
Store Ø(n+1) in place of Ø(n)
S770

FIG. 6B

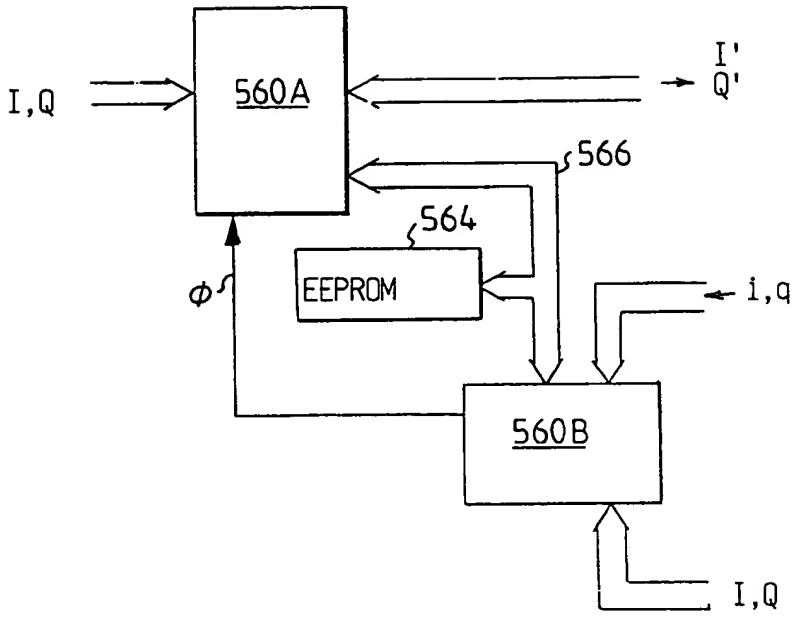


FIG.7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/01991

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H03F 1/32, H03G 3/20, H04L 27/36
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H03F, H03G, H04B, H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EDOC, WPIL, JAPIO, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 9405078 A1 (TELEFONAKTIEBOLAGET LM ERICSSON), 3 March 1994 (03.03.94), page 1, line 33 - page 2, line 18; page 7, line 13 - line 29	1,9,21,29
Y		8,16,17,19, 28,36,37
	--	
X	EP 0731556 A1 (NEC CORPORATION), 11 Sept 1996 (11.09.96), page 3, line 11 - page 5, line 49	1,9,21,29,41
Y		8,10,16-20, 22,28,30,36, 37
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 April 1999	19 -04- 1999
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Bo Gustavsson Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/01991

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y		17,19
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Y	US 5420536 A (MICHAEL FAULKNER ET AL), 30 May 1995 (30.05.95), column 9, line 11 - column 10, line 13, abstract	10,18,20,22, 30
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A	EP 0648012 A1 (LINEAR MODULATION TECHNOLOGY LTD), 12 April 1995 (12.04.95), see the whole document	1,8-10, 16-22,28,30, 36,37,41
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INTERNATIONAL SEARCH REPORT

Information on patent family members

02/03/99

International application No.
PCT/SE 98/01991

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US 5420536 A	30/05/95	AU 5781794 A	22/09/94
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